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Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2015/047

EVALUATION OF SOFT-SHELL DATA FOR LEGAL-SIZED MALE DUNGENESS CRABS (*METACARCINUS MAGISTER*) IN CRAB MANAGEMENT AREAS E, G, AND H IN BRITISH COLUMBIA, 2009-2013

Dungeness Crab (from Hart, J.F.L. 1982. Crabs and their relatives of British Columbia. British Columbia Provincial Museum Handbook No. 40.)

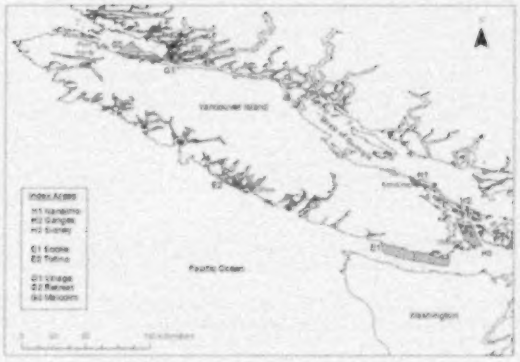

Figure 1. Dungeness Crab biological sampling index areas (in grey) in Crab Management Areas E, G, and H in southern British Columbia, 2009 - 2013.

Context:

Commercial fishing for Dungeness Crabs (Metacarcinus magister) occurs throughout British Columbia (BC). Four Crab Management Areas (CMAs) in BC (B, E, G, H) are not currently managed using seasonal soft-shell closures, as soft-shell timing in these areas was largely unknown. In 2009, two industry-sponsored Dungeness Crab biological sampling programs (fishery-independent (FI) and fishery-dependent (FD)) were carried out in CMAs E, G, and H to identify when crabs are in soft-shell condition. Fisheries Management Branch requested that Science Branch provide an analysis of crab biological data collected during 2009 - 2013 to evaluate the timing and variability of soft-shell occurrence in legal-sized male crabs in CMAs E, G, and H. Legal-sized males were the focus because they are targeted by the fishery, and managers currently do not manage around soft-shell periods for sublegal-sized males and females.

This Science Advisory Report is from the April 21-22, 2015 regional peer review on Evaluation of soft shell data for legal-sized male Dungeness Crab (Metacarcinus magister) in Crab Management Areas E, G, and H in British Columbia, 2009-2013. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

December 2015

Canada

SUMMARY

- DFO crab fishery managers requested information on the soft-shell timing of legal-sized male Dungeness Crabs (*Metacarcinus magister*)[1] in Crab Management Areas (CMAs) E, G, and H.
- Crab biological data collected from ongoing collaborative sampling programs between DFO, the commercial crab harvesters and their service provider, from 2009 to 2013, at index areas in CMAs E, G, and H, were used to evaluate when legal-sized male crabs were in soft-shell condition.
- Data were collected from two sampling programs:
    - a fishery-independent (FI), using standardized trap gear fished independently of the commercial fishery; and,
    - a fishery-dependent (FD) program, where sampling was conducted on commercial vessels while actively fishing.
- Sampling included 19,742 traps hauled during 820 sampling events. Approximately 157,000 Dungeness Crabs were sampled, of which about 18,000 were soft and 28,000 were hard-shell legal-sized males.
- Two analytical methods were used:
    - The proportion method evaluated the proportion of soft-shell legal-sized males to all legal-sized male crabs sampled per sampling event; and,
    - The CPUE method evaluated the catch per unit of effort (CPUE) of soft-shell legal-sized male crabs, defined as the total catch of soft-shell legal-sized males divided by the total number of traps in a sampling event.

  Two Bayesian models, a proportion model and a CPUE model, were fitted to sample data to estimate the timing of peak proportion and peak relative abundance, respectively, of soft-shell legal-sized male crabs (CPUE is used as a proxy indicator of relative abundance of soft-shell legal-sized male crabs in the population). Time periods (including estimates of uncertainty) when the proportion and relative abundance of soft-shell legal-sized males were above various levels, ranging from 0.50 to 0.95 of peak soft-shell, were estimated.
- The proportion model produced longer estimated soft-shell periods than the CPUE model, and results regarding start/end and peak dates, and their 95% credible intervals, were generally less variable and more precise.
- Although soft-shell legal-sized males were observed throughout the year, the estimated peak of soft-shell legal-sized male crabs generally occurred in March.
- High numbers of soft-shell legal-sized male crabs were observed in other seasons, for example, in 2009 a secondary summer peak was observed in some areas.
- Results from the FD and FI sampling programs showed similar trends in peak timing of soft-shell legal-sized male crabs.

[1] *Metacarcinus magister*, formally *Cancer magister*, is accepted as the current taxonomic name for Dungeness Crab (Davie 2015, Schram and Ng 2012).

INTRODUCTION

Dungeness Crabs grow by molting. After shedding their old, hard shells, crabs are left with new, soft exoskeletons, which gradually harden over a period of two to three months. During this soft-shell period, crabs are more vulnerable to being injured and/or killed from interactions with other crabs, encounters with predators, or handling by fishers.

DFO has management measures in place to help protect soft-shell legal-sized male crabs. These measures include non-retention of crabs in all seven CMAs with a shell hardness of less than 70 durometer units, seasonal closures in CMAs A, I, and J, and trap haul restrictions in CMAs E, G, and H.

DFO's Fisheries Management Branch requested that Science Branch provide an analysis of crab biological data collected in 2009 - 2013 from the collaborative sampling programs to evaluate the timing and magnitude of soft-shell occurrence in legal-sized male crabs in CMAs E, G, and H (Figure 1).

Objectives of the Research Document are to:

1. Provide estimates of the proportions and catch per unit effort (CPUE) of soft-shell legal-sized males from fishery-independent and fishery-dependent sampling programs in CMA's E, G, and H from 2009 to 2013.
2. Fit statistical models to sample data to determine population estimates of proportion and relative abundance of soft-shell legal-sized male crabs, including estimates of uncertainty.
3. In the form of decision tables, provide population estimates and timing of peak soft-shell proportion and relative abundance.
4. Discuss sources of uncertainty of this assessment, including the sampling program and data limitations.

ANALYSIS

Data were collected from two sampling programs: 1) a fishery-independent (FI) program, using standardized trap gear fished independently of the commercial fishery; and, 2) a fishery-dependent (FD) program, where sampling was conducted on commercial vessels while actively fishing. Target sampling frequency was twice a month from January to June, and once per month from July to December, for each of the index areas, resulting in 18 sampling events per index area per year. The target sample size was 200 crabs per sampling event. Crabs were sampled for species, sex, shell condition, injuries, mating marks, and carapace notch width. Shell condition was categorized into 8 codes based on degree of shell hardness and shell condition using standard DFO methodology (Dunham et al., 2011). For the analysis, codes were grouped into two states of shell hardness, either "soft" (shell codes 5, 4, 3, or 2) or "hard" (shell codes 1, 8, 7, or 6).

The analysis was restricted to legal-sized male crabs because they are targeted by the fishery, and managers currently do not manage around soft-shell periods for sublegal-sized males and females.The following two analytical methods were applied to the data from both the fishery-independent (FI) and fishery-dependent (FD) sampling programs: 1) proportion of soft-shell legal-sized male crabs to all legal-sized male crabs per sampling event; and, 2) catch per unit of effort (CPUE) of soft-shell legal-sized male crabs, defined as the number of soft-shell legal-sized male crabs per trap per sampling event. Therefore, for each index area and CMA, four analyses were performed (i.e., proportion and CPUE methods applied to both FI and FD sampling programs).

The proportion method describes the proportion of soft-shell legal-sized male crabs to all legal-sized male crabs, but does not give an indication of the relative abundance of soft-shell legal-sized crabs in the population. CPUE is used as a proxy indicator of relative abundance of soft-shell legal-sized male crabs in the population. Since the overall abundance of soft-shell legal-sized male crabs is assumed to change between years, the CPUEs were standardized to a common baseline before models were fitted to the data, allowing data across years to be combined.

Two Bayesian models, a proportion model and a CPUE model, were fitted to the data to estimate the value and timing of peak proportion and relative abundance of soft-shell legal-sized male crabs. The time periods (including estimates of uncertainty) when the proportion and relative abundance of soft legal males were above various levels ranging from 0.50 to 0.95 of peak soft-shell were also estimated (Figure 2). The models combined all index areas and all years for each CMA. Results of the proportion and relative abundance models are presented in Tables 1 and 2, respectively.

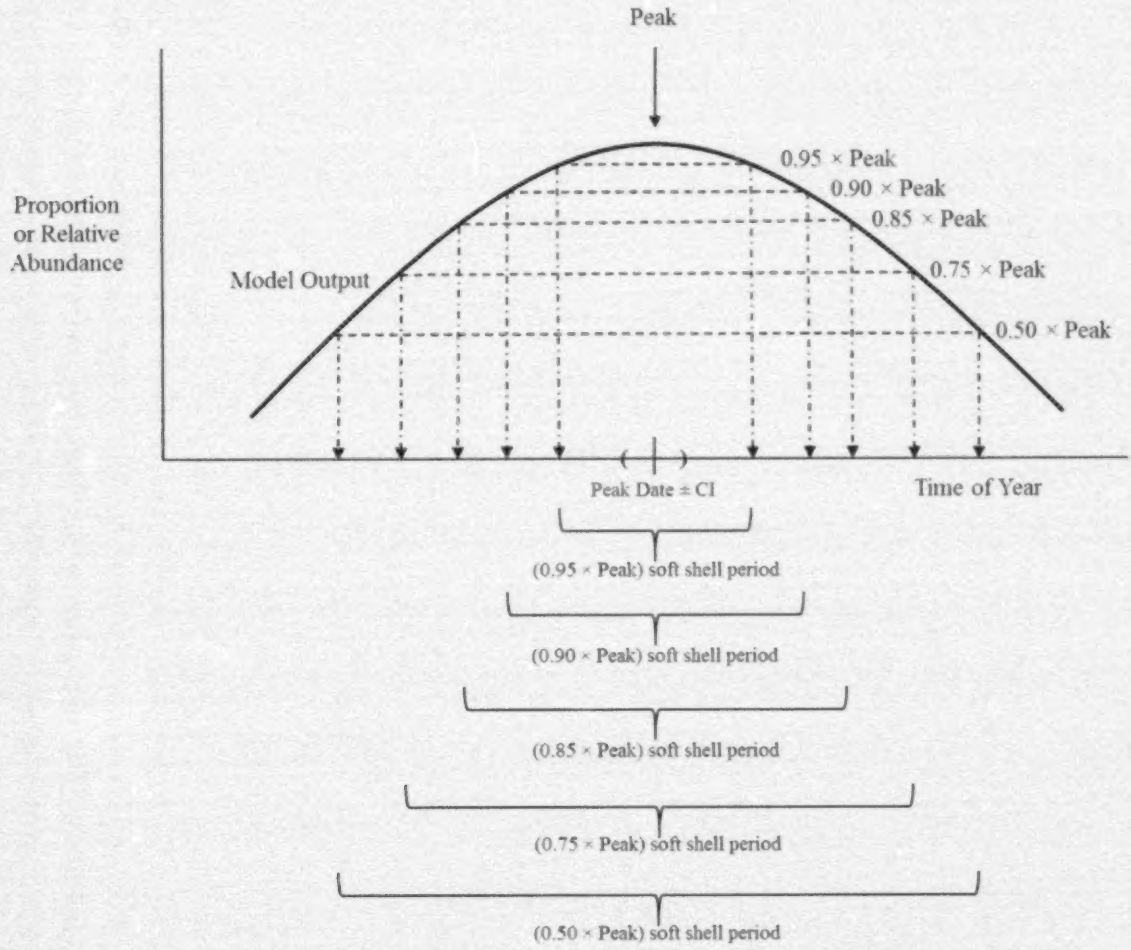

Figure 2. Illustration describing the model output and five reduction level options (from the peak value) and their corresponding dates.

*Table 1. Results of the proportion model for fishery-independent (FI) and fishery-dependent (FD) sampling programs for soft-shell legal-sized male Dungeness Crabs. Peak = proportion and date of maximum proportion; 0.95*Peak, 0.90*Peak, 0.85*Peak, 0.75*Peak and 0.50*Peak = reductions from the peak proportion, or 95%, 90%, 85%, 75% and 50% of the peak proportion, respectively; L95% and U95% = the lower and upper 95% credible interval bounds, respectively, for proportion values; Start Date and End Date = estimated start and end dates of the time period when proportions were at, or above, the particular reduction level from the peak proportion; Peak Date = the date of peak proportion; Variability in Date = 95% credible intervals around the peak date, or around both the start and end dates. Note that the FD results for CMA E-S were not significant so are not included.*

CMA	Sampling Program	Peak & Reduction Levels	Proportion of Soft Legal-sized Males L95%		U95%	Start Date	Peak Date	End Date	Variability in Date (+/- days)	R^2 of model fit	Sample Events (N)
H	FI	Peak	0.38	0.54	0.70	-	Mar 15	-	5		
		0.95*Peak	0.36	0.51	0.67	Feb 07	-	Apr 22	8		
		0.90*Peak	0.34	0.48	0.63	Jan 23	-	May 07	10	0.4082	242
		0.85*Peak	0.32	0.46	0.60	Jan 12	-	May 18	11		
		0.75*Peak	0.28	0.40	0.53	Dec 24	-	Jun 6	13		
		0.50*Peak	0.19	0.27	0.35	Nov 17	-	Jul 13	14		
	FD	Peak	0.36	0.48	0.59	-	Mar 05	-	6		
		0.95*Peak	0.34	0.46	0.56	Jan 23	-	Apr 17	8		
		0.90*Peak	0.32	0.44	0.53	Jan 06	-	May 04	9		
		0.85*Peak	0.31	0.41	0.50	Dec 24	-	May 17	9	0.4098	164
		0.75*Peak	0.27	0.36	0.45	Dec 03	-	Jun 07	11		
		0.50*Peak	0.18	0.24	0.30	Oct 20	-	Jul 21	12		
E-Sooke	FI	Peak	0.53	0.65	0.75	-	Mar 12	-	9		
		0.95*Peak	0.51	0.61	0.71	Jan 31	-	Apr 23	11		
		0.90*Peak	0.48	0.58	0.68	Jan 15	-	May 10	12		
		0.85*Peak	0.45	0.55	0.64	Jan 02	-	May 22	14	0.4427	70
		0.75*Peak	0.40	0.48	0.56	Dec 14	-	Jun 10	15		
		0.50*Peak	0.27	0.31	0.38	Nov 06	-	Jul 18	16		
	FD	Peak	0.50	0.59	0.67	-	Mar 09	-	10		
		0.95*Peak	0.48	0.56	0.63	Jan 19	-	Apr 29	11		
		0.90*Peak	0.45	0.53	0.60	Dec 30	-	May 19	12		
		0.85*Peak	0.43	0.50	0.57	Dec 14	-	Jun 03	13	0.2591	77
		0.75*Peak	0.38	0.44	0.50	Nov 20	-	Jun 28	15		
		0.50*Peak	0.25	0.29	0.33	Oct 02	-	Aug 15	NA		
E-Tofino	FI	Peak	0.30	0.48	0.67	-	Mar 21	-	10		
		0.95*Peak	0.29	0.45	0.64	Feb 11	-	Apr 30	13		
		0.90*Peak	0.27	0.43	0.60	Jan 26	-	May 16	14	0.3226	77
		0.85*Peak	0.26	0.41	0.57	Jan 14	-	May 28	15		
		0.75*Peak	0.23	0.36	0.50	Dec 24	-	Jun 18	17		

CMA	Sampling Program	Peak & Reduction Levels	Proportion of Soft Legal-sized Males L95%		U95%	Start Date	Peak Date	End Date	Variability in Date (+/- days)	R^2 of model fit	Sample Events (N)
		0.50*Peak	0.15	0.24	0.33	Nov 13	-	Jul 29	20		
	FD	Peak	0.37	0.48	0.58	-	Mar 24	-	8	0.4134	60
		0.95*Peak	0.35	0.46	0.55	Feb 12	-	May 06	9		
		0.90*Peak	0.33	0.43	0.52	Jan 26	-	May 23	10		
		0.85*Peak	0.32	0.41	0.49	Jan 13	-	Jun 05	11		
		0.75*Peak	0.28	0.36	0.43	Dec 22	-	Jun 26	12		
		0.50*Peak	0.19	0.24	0.29	Nov 09	-	Aug 09	15		
G	FI	Peak	0.48	0.69	0.88	-	Mar 24	-	5	0.6274	97
		0.95*Peak	0.46	0.65	0.83	Feb 18	-	Apr 28	13		
		0.90*Peak	0.43	0.62	0.79	Feb 05	-	May 12	16		
		0.85*Peak	0.41	0.58	0.74	Jan 25	-	May 22	18		
		0.75*Peak	0.36	0.52	0.66	Jan 10	-	Jun 07	20		
		0.50*Peak	0.24	0.34	0.44	Dec 11	-	Jul 07	20		
	FD	Peak	0.44	0.63	0.80	-	Mar 21		6	0.8678	23
		0.95*Peak	0.42	0.60	0.76	Feb 19	-	Apr 22	10		
		0.90*Peak	0.40	0.57	0.72	Feb 07	-	May 04	12		
		0.85*Peak	0.37	0.54	0.68	Jan 28	-	May 13	13		
		0.75*Peak	0.33	0.47	0.60	Jan 13	-	May 28	14		
		0.50*Peak	0.22	0.31	0.40	Dec 16	-	Jun 26	15		

*Table 2. Results of the CPUE model for fishery-independent (FI) and fishery-dependent (FD) sampling programs for soft-shell legal-sized male Dungeness Crabs. Peak = relative abundance and date of maximum relative abundance; 0.95*Peak, 0.90*Peak, 0.85*Peak, 0.75*Peak and 0.50*Peak = reductions from the peak relative abundance, or 95%, 90%, 85%, 75% and 50% of the peak relative abundance, respectively; L95% and U95% = the lower and upper 95% confidence limits, respectively, for relative abundance values; Start Date and End Date = estimated start and end dates of the time period when the relative abundances were at, or above, the particular reduction level from the peak relative abundance; Peak Date = the date of peak proportion; Variability in Date = 95% credible intervals around the peak date, or around both the start and end dates.*

CMA	Sampling Program	Peak & Reduction Levels	Relative Abundance of Soft Legal-sized Males L95%		U95%	Start Date	Peak Date	End Date	Variability in Date (+/- days)	R^2 of model fit	Sample Events (N)
H	FI	Peak	0.24	0.44	0.69	-	Mar 27	-	13		
		0.95*Peak	0.22	0.42	0.66	Mar 02	-	Apr 23	14		
		0.90*Peak	0.21	0.40	0.62	Feb 19	-	May 03	14	0.1117	242
		0.85*Peak	0.20	0.37	0.59	Feb 11	-	May 11	15		
		0.75*Peak	0.18	0.33	0.52	Jan 28	-	May 25	16		
		0.50*Peak	0.12	0.22	0.35	Dec 29	-	Jun 24	17		
	FD	Peak	0.17	0.50	0.88	-	Mar 15	-	21		
		0.95*Peak	0.16	0.47	0.83	Feb 16	-	Apr 15	23		
		0.90*Peak	0.15	0.45	0.79	Feb 05	-	Apr 27	24		
		0.85*Peak	0.15	0.42	0.74	Jan 26	-	May 06	25	0.2112	164
		0.75*Peak	0.13	0.37	0.66	Jan 11	-	May 21	26		
		0.50*Peak	0.09	0.25	0.44	Dec 09	-	Jun 22	28		
E-Sooke	FI	Peak	0.19	0.43	0.74	-	Mar 14	-	31		
		0.95*Peak	0.18	0.40	0.71	Feb 19	-	Apr 12	32		
		0.90*Peak	0.17	0.38	0.67	Feb 08	-	Apr 22	32		
		0.85*Peak	0.16	0.36	0.63	Jan 31	-	May 01	33	0.2723	70
		0.75*Peak	0.14	0.32	0.56	Jan 16	-	May 15	34		
		0.50*Peak	0.09	0.21	0.37	Dec 16	-	Jun 14	36		
E-Tofino	FI	Peak	0.21	0.48	0.80	-	Apr 15	-	20		
		0.95*Peak	0.20	0.46	0.76	Mar 24	-	May 09	21		
		0.90*Peak	0.19	0.44	0.72	Mar 14	-	May 18	21		
		0.85*Peak	0.18	0.41	0.68	Mar 07	-	May 26	22	0.0096	77
		0.75*Peak	0.16	0.36	0.60	Feb 23	-	Jun 07	23		
		0.50*Peak	0.11	0.24	0.40	Jan 27	-	Jul 03	25		
	FD	Peak	0.17	0.49	0.88	-	Mar 17	-	25		
		0.95*Peak	0.16	0.47	0.84	Feb 23	-	Apr 11	27		
		0.90*Peak	0.15	0.44	0.79	Feb 14	-	Apr 21	27		
		0.85*Peak	0.14	0.42	0.75	Feb 06	-	Apr 28	28	0.2981	60
		0.75*Peak	0.12	0.37	0.66	Jan 24	-	May 11	28		
		0.50*Peak	0.08	0.25	0.44	Dec 28	-	Jun 06	30		
G	FI	Peak	0.13	0.45	0.91	-	Mar 24	-	18	0.1852	97

CMA	Sampling Program	Peak & Reduction Levels	Relative Abundance of Soft Legal-sized Males L95%		U95%	Start Date	Peak Date	End Date	Variability in Date (+/- days)	R^2 of model fit	Sample Events (N)
		0.95*Peak	0.12	0.43	0.86	Mar 03	-	Apr 17	20		
		0.90*Peak	0.12	0.41	0.82	Feb 21	-	Apr 26	21		
		0.85*Peak	0.11	0.39	0.77	Feb 14	-	May 03	22		
		0.75*Peak	0.10	0.34	0.68	Feb 02	-	May 15	23		
		0.50*Peak	0.06	0.23	0.45	Jan 07	-	Jun 10	24		
	FD	Peak	0.55	0.84	0.99	-	Mar 22	-	22		
		0.95*Peak	0.52	0.79	0.94	Feb 20	-	Apr 22	27		
		0.90*Peak	0.50	0.75	0.89	Feb 09	-	May 03	27	0.6557	23
		0.85*Peak	0.47	0.71	0.84	Jan 31	-	May 11	27		
		0.75*Peak	0.41	0.63	0.74	Jan 18	-	May 24	27		
		0.50*Peak	0.28	0.42	0.50	Dec 24	-	Jun 17	28		

Sources of Uncertainty

- Defining soft shell crabs – In this paper, soft-shell crabs are defined as those crabs with shells that were soft to any degree whatsoever (shell condition codes 5, 4, 3 and 2). Some crabs assigned shell code 2 are sufficiently hard to be legally retained by industry, so from a market perspective these crabs are not soft. The assignment of shell hardness codes is also somewhat subjective, creating additional uncertainty. As a result, the model output may have produced slightly later end dates for estimated soft-shell periods presented in Tables 1 and 2 than those that may have resulted if marketable crabs could have been excluded from shell code 2.
- Interannual variability - The year 2009 was unusual compared to the other four years of the study because the spring soft-shell period occurred later, and there was a notable secondary soft-shell period observed during the summer in most, but not all, index areas. This was observed in all index areas in CMA H, Tofino (CMA E), and Malcolm Island (CMA G), but not in Sooke (CMA E) or Village Channel (CMA G). There were secondary peaks observed during the summer in other years, but they were not as prominent. Reasons why this secondary soft-shell period was so large in 2009 are unknown. Although 2009 was unusual within the dataset, harvesters report that secondary soft-shell periods are not uncommon.
- Sampling frequency was lower in the FD sampling program, and gaps between sampling events during late fall and winter months may have affected the model's ability to produce biologically meaningful outputs. Increased sampling frequency would likely improve accuracy of the estimation of soft-shell timing for the population.
- Effects of commercial harvesting of hard-shelled crabs within the sampling areas on estimated soft-shell proportions and relative abundance are unknown.
- It is unknown how variability, within and among sampling programs (such as fisher experience, ocean temperature, bait type, soak time, fishing locations, etc.), may have affected observed data and, in turn, the model's ability to predict when legal-sized male Dungeness Crabs were in soft-shell condition.

CONCLUSIONS AND ADVICE

- Although legal-sized male Dungeness Crabs were observed in soft-shell condition at almost any time of the year, the estimated peak in proportion and relative abundance of soft crabs generally occurred in March.
- High numbers of soft-shell legal-sized male crabs were observed in other seasons, for example, in 2009, a secondary summer peak was observed in 5 of the 8 index areas.
- FI and FD sampling programs showed similar observed trends in peak timing of soft-shell legal-sized males.
- Results derived from FI proportion method may better describe when legal-sized male Dungeness Crabs are in soft-shell condition.
- Results derived from the FD CPUE method best describe when the commercial fleet catches high numbers of soft-shell legal-sized male crabs.
- The proportion model produced longer estimated soft-shell periods, more precise start/end dates and peak dates, and had a higher degree of certainty in model predictions than the CPUE model.
- Results are summarized in tables providing the 95% credible intervals for peak soft-shell dates and start/end dates of the soft-shell period as defined by a range of reduction levels

(0.50 to 0.95 of the peak value) for each CMA for both proportion and relative abundance models.

- Further research to understand environmental determinants of the observed interannual variability in Dungeness Crab soft-shell periods in BC may reduce uncertainty around estimates.
- Biological sampling programs, designed to determine crab soft-shell periods with high certainty, require consistent and frequent sampling of sufficient numbers of crabs throughout the year to produce meaningful results.
- The identification of measurable population health and sustainability objectives is required in order to inform future research that will quantitatively determine the efficacy of potential management measures.

SOURCES OF INFORMATION

This Science Advisory Report is from the April 21-22, 2015 regional peer review on Evaluation of soft shell data for legal-sized male Dungeness Crab (*Metacarcinus magister*) in Crab Management Areas E, G, and H in British Columbia, 2009-2013. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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ISSN 1919-5087
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Correct Citation for this Publication:

DFO. 2015. Evaluation of soft shell data for legal-sized male Dungeness Crab (*Metacarcinus magister*) in Crab Management Areas E, G, and H in British Columbia, 2009-2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/047.

Aussi disponible en français :

MPO. 2015. Évaluation des données sur la carapace molle des crabes dormeurs (Metacarcinus magister) mâles de taille réglementaire dans les zones de gestion du crabe E, G et H en Colombie-Britannique, de 2009 à 2013. Secr. can. de consult. sci. du MPO, Avis sci. 2015/047.